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Edwards Street Laboratory
Yale University
New Haven, Connecticut

ESL Technical Memorandum No. 33
(ESL:521:Ser 03)
23 March 1954

Notes on a Detection System Similar To That Proposed by W.G. Wadey And Tested at Beavertail During the Summer of 1953

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Technical Memoranda are issued as informal internal memoranda on matters of limited interest to give preliminary or interim information which may later be embodied in a more formal report by this Laboratory. They do not necessarily represent the final views of the project nor are they to be regarded as definitive.

A scheme for the detection of vessels crossing the entrance to a harbor is described by L.B. Slichter and L. Batchelder in a BuShips memorandum "Method of Harbor Protection Against Non-Magnetic Submarines". The scheme is similar in some ways to the scheme proposed in TM No. 9 HPP:520, Serial 0042 by W.G. Wadey. It comprises a long relatively narrow low-frequency transmitting coil stretching across a harbor mouth or a ship channel with a number of receiving coils dispersed along its center line. The receiving coils are paired off in such a way as 1-6, 2-7, 3-8 ... and are connected so that the voltages induced in each pair are in opposing phase. Thus under normal conditions no signals appear in the outputs from the coil pairs. When a vessel constructed of or carrying large masses of conducting material passes over, currents are induced in the conducting material which react to upset the delicate balance of signals induced in the receiving coils. The memorandum describes tests made with a single pair of receiving coils and a transmitting coil laid across the bottom of the ship channel into Boston Harbor. The operating frequency was 10 cps, input power 1.8 kw, and the detector of unbalance signals was a sensitive d-c galvanometer measuring the current rectified by a switch driven synchronously at 10 cps. There were some further refinements in the way of phase and amplitude adjustment. Results confirmed approximate theoretical calculations predicting that a vessel should be detectable with this apparatus

at ranges up to as far as its own length. The memorandum is of interest because it should cast some light on the sensitivity to be expected of the Wadey system if turned to a similar use.

The most essential difference between this scheme and Wadey's is that this one begins with the concept of an alternating magnetic field set up in the medium, this magnetic field being perturbed by "dipoles" induced in conducting masses present, whereas Wadey's begins with the concept of an alternating current field, with "dipoles" generated by inhomogeneities in the conductivity of the medium. However, since sea water is an appreciably good conductor, yet not a perfect conductor, it will be impossible to have a pure case of one or the other. Currents in the medium are bound to flow in the first case, and to be displaced by conducting or non-conducting hulls, and, in the second case, induction effects are bound to occur, as in the situation of a vessel with an insulating hull but with conducting contents such as engines, wiring, etc.

Both systems may be considered as bridges which balance two transmission paths one against the other in order to show up small perturbations in one path or the other. The present state of the theory allows no definite conclusions, but I do not believe that that exact method of generating the primary field should make any extraordinary difference to the detection sensitivity of the system. (The current field for the Wadey system

was set up by a pair of long parallel bare electrodes.) Similarly I do not believe that the exact form of receiving device, whether coil or electrode-pair, should make any extraordinary difference. (Wadey originally proposed using electrodes, but the first experiments toward detection were made with coil pickups.) Of course there will be some differences due to the degree to which one effect predominates over another, and these differences will depend on frequency, depth, distance, and so on, but a much better theoretical understanding of the medium and its boundaries is needed before the significance of the differences can be assessed. Setting up the primary field by means of a long narrow coil as described by Slichter and Batchelder has definite attractions, especially for a fence across a harbor mouth, since it establishes a uniform field along the entire distance in the simplest possible way. If electrodes are used, special means must be taken to prevent a serious falling-off of field strength down the length of the system.

The authors seem unconscious of the fact that they must be gaining greatly in noise figure by using a synchronous, or "phase-sensitive" rectifier. It is one of the more important inherent advantages in using a low-frequency alternating field artificially set up in the medium - as opposed to D.C. devices and "listening" devices - that one is dealing with a known coherent frequency to be picked out from the ambient random noise.

From what we know at this stage it is practically impossible

to estimate the ultimate limits of sensitivity of these schemes. I should say that the estimate by Slichter and Batchelder of a possible improvement of at least 100 times in sensitivity of their device (a factor of 4.6 in range, they say) is conservative. However, their estimate was based on being able to detect an unbalance between the signals from the two coils of one part in 1000. If the modifications for greater sensitivity consisted only in increasing the effective signal level throughout the system (such as by increasing input power, coil area-turns, detector amplification) the system would then have to be assumed capable of revealing an unbalance of one part in 100,000. A stability of balance of this order in a bridge in which the uncontrollable and somewhat variable properties of the harbor water play a considerable part, may be a lot to expect. Many very slow variations could be compensated for by automatic balancing circuitry but it would remain for actual test to show to what extent the unstable factors could be overcome. It is also conceivable that a further gain in sensitivity could be achieved if the signals from passing vessels shared some typical characteristic, such as a typical phase shift with respect to the phase of the exciting field. The unbalance detector could then be made specially sensitive to signals of that phase. But this is enough to show that these estimates should not be taken too seriously. Ultimately, the only way to settle satisfactorily how far these systems can be practically improved and extended

is to use them and play with them - continuously over a long period of time.

The scheme of Slichter and Batchelder as described in this paper, and this applies also to the Wadey scheme as it stands at present, appears cumbersome and expensive because of the many large receiving coils and their many leads to shore. It might be reasonable to hope that the multiplicity of elements in the receiving system could be reduced if less information were needed regarding just where along the fence a vessel passed.

This evaluation may seem very indefinite but that, I should say, is consistent with the present state of the art. For example, the paper discussed contains practically no information on phase shifts in the medium, phase shifts in signals from various tragets, and no information on responses to ambient or instrumental noise that might be mistaken for responses to passing ships. How many ships would they say had gone past if they had not been watching with theodolites?

Our experiments have been conducted with electronic balancing and detecting circuits rather than with a simple galvanometer scheme as used by Slichter and Batchelder, but the system has not been set up and working for long enough to have exploited fully the possibilities of present-day low-noise electronic circuitry and feedback systems. That is to say, the development of the apparatus has not yet been carried to the practicable threshold.

Thus the reports now in preparation on the Beavertail detection experiments to date will have little more to add in the way of detailed information on the possible limits of sensitivity.

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